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ADJUSTMENT OF PEAK DISCHARGE RATES FOR URBANIZATION.(U)
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TECHNICAL PAPER NO. 54

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ADJUSTMENT OF PEAK DISCHARGE RATES FOR URBANIZATION

by

DAVID L. GUNDLACH

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Paper No. 54
2. GOVT ACCESSION NO.: AD-A106253
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): ADJUSTMENT OF PEAK DISCHARGE RATES FOR URBANIZATION
5. TYPE OF REPORT & PERIOD COVERED:
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): David L. Gundlach
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Corps of Engineers, The Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS:
12. REPORT DATE: February 1979
13. NUMBER OF PAGES: 7
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Distribution of this publication is unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES: This paper is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 104, No. IR3, September 1978.
19. KEY WORDS (Continue on reverse side if necessary and identify by block number): Urbanization, Peak discharge, Hydrograph analysis, Urban hydrology, Model studies, Watersheds(Basins), Floods, Surface runoff, Runoff, Storm runoff, Hydrologic aspects, Analytical techniques.
20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Various investigators have shown that changes from rural to urban conditions within a watershed, in general, significantly affect flood flows. Recorded annual peak discharge rates (or peak discharge rates above a given base) for a basin that has been undergoing a change in land-use conditions represent a nonstationary time series. The series must be adjusted to a specific land-use condition (typically present conditions) prior to performing a statistical frequency analysis. It was the aim of this (Continued)

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note to present a procedure utilizing a single event rainfall-runoff model for transforming recorded peak discharges at a gaging station to a consistent se that reflects existing land-use conditions. Methods presented can be used as a guide to determine an existing-condition discharge frequency curve of annual peaks (or peak discharge rates above a given base) when utilizing a single event rainfall-runoff model. The multiplan-ratio option of HEC-1 permits the user to calculate systematically the hydrologic response of several storm events for a given set of land-use conditions. The adjustment procedure described is also applicable when predicting runoff for estimated future conditions.

Adjustment of Peak Discharge Rates for Urbanization

By David L. Gundlach,[1] A. M. ASCE

Introduction

Various investigators (1,4,5,7) have shown that changes from rural to urban conditions within a watershed, in general, significantly affect flood flows. Recorded annual peak discharge rates (or peak discharge rates above a given base) for a basin that has been undergoing a change in land-use conditions represent a nonstationary time series. The series must be adjusted to a specific land-use condition (typically present conditions) prior to performing a statistical frequency analysis. It is the aim of this note to present a procedure utilizing a single event rainfall-runoff model for transforming recorded peak discharges at a gaging station to a consistent set that reflects existing land-use conditions.

Adjustment of Recorded Peak Discharge Rates

In general, when a single event rainfall-runoff computer program such as the one in Ref. 2 is utilized to develop a calibrated basin model, the procedure involves the reconstitution of several flood hydrographs at a particular streamflow gaging station. If significant urbanization has taken place in the basin over time, it becomes necessary to reconstitute flood events that have occurred in a given time frame so that the effect of land-use change on the hydrologic regime within that time frame can be considered negligible. In most urbanizing watersheds there is more hydrologic and physiographic data available for recent years, such that it is normally expedient to calibrate a hydrologic basin model for present (or existing) conditions.

Results obtained from Ref. 3 are used herein to illustrate the technique for adjusting recorded peak discharge rates. Ref. 2 was utilized to reconstitute three *recent* flood hydrographs at the United States Geological Survey recording streamflow gage, at Rahway River near Springfield. In this case the resulting calibrated hydrologic basin model represented 1970 conditions.

Note.—Discussion open until February 1, 1979. To extend the closing date one month, a written request must be filed with the Editor of Technical Publications, ASCE. This paper is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 104, No. IR3, September, 1978. Manuscript was submitted for review for possible publication on December 13, 1977.

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By adjusting various parameters the calibrated data model can, in a representative way, simulate runoff from land-use conditions that existed in the basin prior to 1970. This is accomplished by modifying the adopted parameters that characterize the routing procedures, unit hydrographs, precipitation loss rate functions, impervious surfaces, and contributing drainage areas. Adjustment of routing criteria is dependent upon changes to the main channel system such as the construction of concrete channels, flood control structures, etc. In the Rahway study (3), unit hydrograph parameters [Clark method (2)] were modified

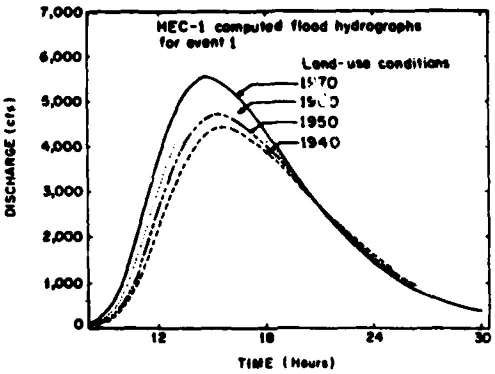

FIG. 1.—Simulated Flood Hydrographs for Various Land-Use Conditions

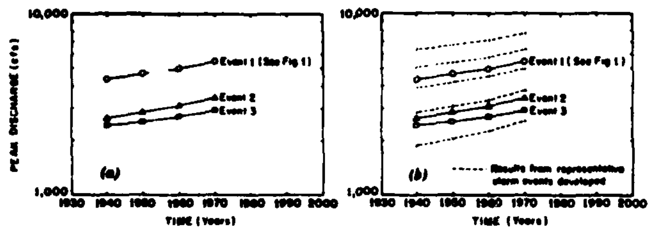

FIG. 2.—Effect of Urbanization on Peak Discharge Rates

according to the following relationships based on a multiple regression analysis of regional data:

$$\frac{(TC)_1}{(TC)_2} = \left(\frac{1 + 0.03I_2}{1 + 0.03I_1}\right)^{1.28} \quad (1)$$

$$\frac{(TC + R)_1}{(TC + R)_2} = \left(\frac{1 + 0.03I_2}{1 + 0.03I_1}\right)^{0.67} \quad (2)$$

(Eqs. 1 and 2 relate the direct runoff hydrograph parameters, TC and R, to an indice of urbanization, I, in which TC represents the time of concentration, in hours; R represents the basin storage characteristics, in hours; and I is the percentage of man-made impervious surface within a subbasin. Subscripts 1

and 2 refer to different points in time.) Loss rates were developed as functions of the percent of man-made impervious areas; and contributing drainage areas were modified over time because of changes in drainage patterns due to highway construction and channel realignment.

Since three storm events and their resulting flood hydrographs were utilized in the calibration process, it was a relatively simple matter to use these events to reconstruct flood hydrographs for prior land-use conditions in the basin. Modifying the necessary parameters, as previously cited, the hydrologic responses to the three storm events were simulated for past conditions. The results for one event are shown in Fig. 1 and the peak discharge rates for all three events are plotted versus time in Fig. 2(*a*).

Because of the wide spatial and temporal variation in precipitation and in the loss rate functions adopted for the specific storm events analyzed, the rate of change of peak discharge with urbanization, as reflected by the slope of the curves in Fig. 2(*a*), could be significantly different for other rainfall events (distributions) producing nearly the same peak runoff under existing conditions. Since the curves are approximately parallel, representative (synthetic) rainfall

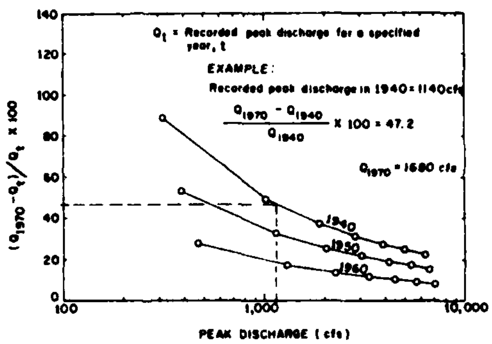

FIG. 3.—Rate of Change of Peak Discharge with Time

events were developed to determine the adjustment of peak discharge rates for urbanization.

An analysis of the rainfall estimates contained in Ref. 8 for the study area indicates that a *general* and *systematic* method exists for simulating the rainfall pattern for numerous events given any single event. By taking ratios of the rainfall amounts for various durations (30-min, 1-hr, 3-hr, 6-hr, 12-hr, and 24-hr) of a specific recurrence interval, the rainfall amounts for respective durations of different recurrence intervals can be determined within reasonable limits. As an example of this procedure, a 2-yr storm pattern can be developed from a 50-yr pattern according to

$$(P_i)_2 = (P_i)_{50}\frac{R_2}{R_{50}} \qquad (3)$$

in which P = storm rainfall amount for a specified duration, in inches; i = duration interval, in hours; R = total storm rainfall for a 24-hr period, in inches;

and subscripts 2 and 50 designate the 2-yr and 50-yr recurrence intervals.

The preceding concept of taking ratios of precipitation ordinates was utilized to develop representative storms ranging from about the 1-yr event to the 500-yr event. A representative 50-yr event (with adjustments for drainage area size according to Ref. 8) was used in conjunction with the multiplan-ratio option of HEC-1. Loss rate functions were developed based on those used in the reconstitution analysis for event 1 (Fig. 1) since the storm rainfall totals and distribution patterns were relatively similar. Seven ratios of the 50-yr storm event were computed for each of the land-use conditions analyzed (1940, 1950, 1960, and 1970) and the results plotted in Figs. 2(*b*) and 3.

Fig. 2(*b*) compares the rates of change of peak discharge with time between the specific storm events analyzed and the representative storm events developed. Fig. 3 can be used to modify the recorded peak discharge for any particular year to a peak discharge consistent with 1970 conditions. From the results shown it is apparent that urbanization has a significantly greater impact on the more frequent events.

Stankowski (7) developed regional expressions, from data which included streamflow records for the Rahway River Basin, relating the annual peak discharge for a given recurrence interval to an index of man-made impervious cover. Application of Stankowski's regional expression yields results that are in general agreement with the HEC-1 results shown in Fig. 3.

The methodology incorporated in this technical note has just recently been applied in preliminary hydologic investigations. For example, the Red Run Drain study (6) utilized similar procedures. In that study the basin model representing past conditions was verified (where adequate data were available) by reconstituting several historical events during each representative time frame.

Summary and Conclusions

Methods presented in this paper can be used as a guide to determine an existing-condition discharge frequency curve of annual peaks (or peak discharge rates above a given base) when utilizing a single event rainfall-runoff model. The multiplan-ratio option of HEC-1 permits the user to calculate systematically the hydrologic response of several storm events for a given set of land-use conditions. The adjustment procedure described herein is also applicable when predicting runoff for estimated future conditions.

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